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Hand-arm vibration from cutting different tree species using battery powered and petrol engine chainsaws

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Abstract

The aim of the research was to determine the magnitude of the transmission rate of hand-arm vibration levels onto the operator from using a petrol chainsaw and battery-powered chainsaw, and to specify the extent to which HAV values in these chainsaw types differ from each other on both the front and rear handles. It was also studied whether the HAV levels differ at cutting different tree species. Two chainsaws were chosen for the research with a nearly identical performance but a different type of drive system (petrol and battery). Measurements were made on six forest tree species of comparable logs diameter and comparable wood moisture content. All cuts were carried out with using the same type of saw chain and the same type of saw bar. Cutting was at all times made by the same operator. The measurements were in line with standards EN ISO 22867, EN ISO 5349-1 and EN ISO 5349-2 and performed with using an instrument certified for the given purpose. Research results showed that the highest HAV level recorded on the front handle from cutting pine with the battery-powered chainsaw was 8.8500 m/s^2. The lowest HAV level (0.7400 m/s^2) affected the operator from cutting hornbeam with the use of petrol chainsaw. The results also indicate that HAV levels of the battery-powered chainsaw are higher than those recorded in the petrol chainsaw.

Key words: HAV; battery-powered chainsaw; petrol chainsaw; wood density; occupational hygiene; forestry

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1. Introduction

Groups of occupations with a high risk of occupational accidents and diseases include chainsaw operators in forestry. It is given by the forest environment itself as working in the forest tends to be dangerous (Slappendel et al. 1993), namely working with the chainsaw which poses health risks to operators. Working with the chainsaw in the forest is used because of several reasons such as difficult access to heavy machinery in some steep terrains, relatively low purchasing cost of chainsaw and its versatile use (Spinelli et al. 2006; Liepiņš et al. 2015), its relatively long life (Calvo et al. 2013), unavailability of modern technologies or poor technology level in underdeveloped countries (Landekić et al. 2019). These days, when the work safety employs high standards of occupational health safety not only in forestry, tree felling with the use of chainsaw still remains a dangerous activity (Tsioras et al. 2014).

Apart from the occupational accidents and injuries (Laschi et al. 2016), operators of chainsaw in the forest are also exposed to the factors of their working environment. In this environment, they move around mainly on foot, which may cause fatigue and risk of slipping, tripping and associated injuries in combination with carried working tools for tree felling. The operators are also affected by weather that may cause discomfort (Tsioras et al. 2014). Nevertheless, the main problems for chainsaw operators are health risks in the form of hand-arm vibrations (HAV) and noise. Exactly these risks are often underestimated by chainsaw operators and not considered to be threatening their health. Papandrea et al. (2022) justify this by the fact that negative effects of HAV and noise do not come up quickly after the exposure but only in the course of time.

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Vibrations transmitted through the chainsaw handle can cause blood flow disorders in the fingers (Vibration White Finger VWF)/ (Albizu-Urionabarrenetxea et al. 2013; Neri et al. 2018), numbness of hands and arms, tingling fingers and impaired tactile perception of fingers (Seppäläinen 1972; Brammer & Pyykkö 1987), disorders of the neurological functions and movements of hand and arm (Matache et al. 2020) or vascular disorders – white fingers (Bovenzi 2008). Other studies (Brammer & Pyykkö 1987; Bovenzi et al. 1991; Bovenzi et al. 2000) revealed several connections between the exposure to HAV and carpal tunnel syndrome, and bicipital tendinitis and epicondylitis in forest workers.

The reduced exposure to HAV in chainsaws can be achieved through using advanced fuels with a more efficient combustion process, which results in lower vibration amplitudes, or through enhanced technology of engine design (Calcante et al. 2018). According to (Goglia et al. 2012a, 2012b), the level of chainsaw vibrations is affected by a number of parameters (operator, way of holding the saw, saw bar length, saw chain tension, amount of fuel in tank). The main source of vibrations in the chainsaw is however the back-and-forth movement of the piston (Kováč et al. 2018). Landekić et al. (2020) add that a firm grip of chainsaw handle may influence the transmission of vibrations from the chainsaw onto the operator. Nevertheless, this fact depends on the operator's experience, work operations and wood hardness (Landekić et al. 2020). Kováč et al. (2018) warn that inappropriate chainsaw operation such as neglected maintenance and missing safety equipment can worsen the HAV effects. Another possible measure consists in using anti-vibration gloves. Sceptical about them however are Hewitt et al. (2016) and Shibata (2017) who claim that the effect of anti-vibration gloves on the level of vibrations can be hardly quantified because it depends on many factors such as operator, grip strength, type of gloves and their age, frequency and direction of vibrations (Hewitt et al. 2016; Shibata 2017).

The battery-powered chainsaw is a source of vibrations only during the process of cutting. In contrast, the petrol chainsaw also generates vibrations outside the cutting process, i.e. when the operator moves around in the forest stand, in time between cutting-off branches etc. This is given by the fact that the engine of the petrol chainsaw is permanently running (idling) but the engine of the battery-powered chainsaw runs only in the moment when the operator presses the throttle trigger. An important question is how much HAV is transmitted onto the chainsaw operator using these two types of saws (petrol and battery-powered) at cutting different tree species and whether the HAV values differ between them. Also, which of the two chainsaw types (petrol and battery-powered) poses a greater risk for the operator and to what extent the HAV values transmitted from the two chainsaw types differ. Answers to these questions are sought in this research.

2. Material and methods

The aim of this research was to find out how much of hand-arm vibration is transmitted onto the chainsaw operator. Namely, how much the HAV levels generated by the petrol chainsaw and battery-powered chainsaw differ from each other on the front handle (FH) and on the rear handle (RH). It was also investigated whether the HAV levels differ at cutting different tree species. Six forest tree species chosen for the research included pedunculate oak (*Quercus robur* L.), European beech (*Fagus sylvatica* L.), European hornbeam (*Carpinus betulus* L.), Scots pine (*Pinus sylvestris* L.), European larch (*Larix decidua* Mill.) and small-leaved linden (*Tilia cordata* Mill.). These tree species were cut by the two chainsaw types. Data were collected in the City of Brno cadastral area in the Czech Republic.

To obtain as much unbiased results as possible, the tree species chosen for research had nearly identical wood moisture content (26.1–37.5%) which was measured in the middle of the logs by the instrument certified for such measurements (Greisinger GMH 3810) with a measurement accuracy of ±0.2%. All wood samples were in the form of logs with a mid-diameter of 14–17 cm. The length of the logs was 60 cm.

2.1. Chainsaw

Two types of chainsaw with different drives were chosen for this research. One of them was battery-powered chainsaw (BP) model Stihl MSA 200C and the other one was petrol (P) chainsaw model Stihl MS 170. The two chainsaw types have comparable characteristics (Table 1).

The two chainsaws used the same type of saw chain for cutting as well as the same guide bar and the same saw blade. Their technical condition was comparable. Before starting the measurements, both chainsaws were adjusted according to instructions supplied by the manufacturer and then the saw chain was mounted on them. Engines of both chainsaws were brought to operating temperature before starting the measurements.

2.2. Measurements

To obtain unbiased results, the logs were always cut by the same person for the entire time of measurements. The operator started to cut the wood samples using the battery-powered chainsaw first and then continued with the petrol chainsaw. The samples were gradually fixed on the testing bench where they were then cut. Their security on the testing bench was necessary to prevent their release or rocking during the process of cutting. The cutting of each sample began from the upper part of the logs in a vertical direction by which slices of wood

Table 1. Technical specifications of chainsaws.

	Stihl MSA 200C	Stihl MS 170
Power	1.5 kW	1.3 kW
Chain speed	16.11 m s^{-1}	14.39 m s^{-1}
Saw-bar length	30 cm	
Saw-bar type	Stihl Rollomatic E Mini	
Chain type	71 PM3 (type 3670)	
Chain pitch	3/8"	
Drive -link thickness	1.1 mm	
Number of drive links	64	
Fuel supply	Electricity (battery)	Mixed (gasoline + oil)
Battery/Fuel type	AP 160 Lithium-Ion	Aspen 2
Total weight *	5.25 kg *	5.30 kg **
Sprocket tooth count	6	8

Note: *with accumulator and cutting part, ** with operating fluids and cutting part.

were produced of about 2 cm in thickness. Each wood sample was then cut across on ten points. It follows that each wood sample was subjected to ten cross cuts. As soon as the tenth sample of the given tree species was cut, the sample was removed from the testing bench to be replaced with another sample of another tree species. Recording of HAV transmission values onto the chainsaw operator (process of cutting) started at the moment when the saw chain touched the wood sample at the first cross-cutting of the given sample and ended at the moment when the operator completed the cross-cutting of the tenth sample. HAV transmission was recorded also during the full throttle of both chainsaw types and idle run in the petrol chainsaw. In the battery-powered chainsaw the HAV level was not recorded as this type of chainsaw has idle running which is not available.

Practical measurements of HAV transmissions were for the entire time of experiment in line with valid standards for the given measurements – EN ISO 22867, EN ISO 5349-1 and EN ISO 5349-2 (EN ISO 22867; EN ISO 5349-1; EN ISO 5349-2). HAV transmission was recorded using two accelerometers certified for the given measurements Datalogger CEM model DT-178 A. In accordance with the standard (EN ISO 5349-2), the accelerometers were fixed to specific points (Fig. 1) on the chainsaw that are stipulated by ISO 22867 (EN ISO 22867). Based on EN ISO 22867 (EN ISO 22867), the accelerometer on the front handle was located 25 mm ±3 mm to the left from the guide bar plane. The accelerometer on the rear handle was located 20 mm ±3 mm in front of the rear throttle trigger. This location was precisely according to EN ISO 22867 (EN ISO 22867), too. The HAV measurements were not affected by weather conditions as they were carried out under laboratory conditions. The air temperature was 19.8 °C.

2.3. Statistical analyses

Data collected from measuring vibrations affecting the chainsaw operator were divided according to the chainsaw types used for cutting (petrol and battery-powered chainsaws) and according to the tested tree species. In addition to this classification, vibrations were specified that were caused by maximum rotations of the chainsaws, by idle run of the petrol chainsaw and by being recorded on the particular chainsaw handle (front/rear). The data were then mutually compared between the handles for possible differences.

For these purposes, a data analysis was performed in the STATISTICA 14 software made by TIBCO. The data were first subjected to the Shaphiro-Wilk test for their correct rating. The test was used to verify whether the distribution of data in the file is normal or is not. Then the data were evaluated as with normal distribution if the result exceeded the set-up p-value of 0.05 (significance level 5%). In case that the data featured normal distribution, a following test was one-factor ANOVA with the p-value set up to 0.05 again. Vibrations from individual cuttings differed from each other if the result of the statistical test did not exceeded the set-up value. When the result of the Shaphiro-Wilk test was lower than

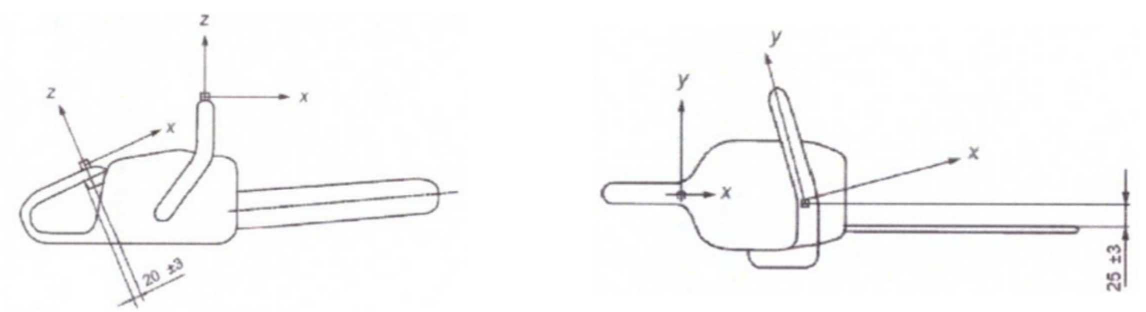

Fig. 1. Location of accelerometers on the chainsaw (EN ISO 22867).

the p-value set up therein, the data did not correspond to the mentioneddistribution. In that case, a non-parametric test was used, namely the Kruskal-Wallis test whose p-value was 0.05 again. Levels of vibrations differed in individual cases if the test result did not exceeded the p-value. Descriptive statistics were performed for individual partial data and box plots were produced for better data depiction.

3. Results

Fig. 2 presents data from the measurement of vibration acceleration (vibrations) on the respective handles, affecting the chainsaw operator at cutting wood samples with the petrol chainsaw and the battery-powered chainsaw. The highest level of vibrations (8.8500 m/s^2) was recorded on the front handle when cutting pine with the battery-powered chainsaw. The lowest value of vibrations (0.7400 m/s^2) was recorded on the front handle as well, and affected the operator when cutting hornbeam with the petrol chainsaw. Looking closer just on the rear handle, one can see higher levels of minimum vibrations with the lowest vibration being 1.0100 m/s^2. The operator was exposed to this vibration again whilst cutting hornbeam with the petrol chainsaw. The highest vibration on the rear handle (6.8500 m/s^2) was recorded when cutting beech with the battery-powered chainsaw. Fig. 2 shows a dense concentration of data on the rear handle of petrol chainsaw in the mode of idling. The data ranged from 2.7500 to 3.4300 m/s^2. In contrast, a sparse data concentration is situated on the front handle when the battery-powered chainsaw is used to cut Scots pine.

Vibrations produced by the petrol chainsaw and battery-powered chainsaw from cutting diverse tree species were mutually compared in our research. In total there were 105 possible combinations of which 67 were classified in the statistical test as different (63.81%). The results indicated that the battery-powered chainsaw reached higher vibration levels than the petrol chainsaw. Vibrations recorded in the petrol chainsaw ranged mostly from ca. 1.0000 to 3.0000 m/s^2. Vibrations recorded in the battery-powered chainsaw ranged from 3.0000 to 6.0000 m/s^2.

Tables 2 and 3 present results of the statistical analysis and comparison of individual vibrations generated from cross-cutting different tree species in different modes. The first activity to be compared was the cutting of beech with the use of battery-powered chainsaw. The average vibration level recorded on the front and rear handle respectively was 5.2986 m/s^2 and 4.7920 m/s^2 (Table 4). Comparing the other activities, it was statistically demonstrated that eight of combinations differed from a total of 14 possible ones in both battery-powered chainsaw handles at cutting beech (Tables 2 and 3). The vibration

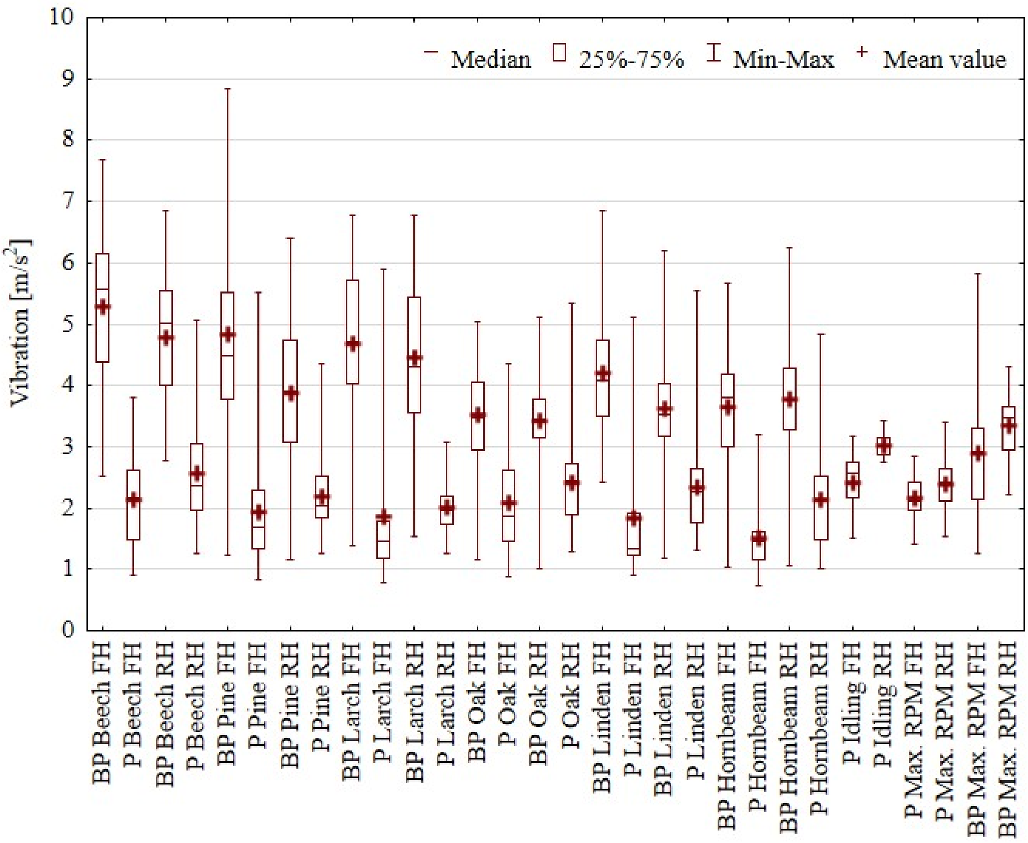

Fig. 2. Distribution of vibration data in measurements.

Table 2. Results of statistical comparison – Front handle.

Chainsaw/tree species	BP Beech	P Beech	BP Pine	P Pine	BP Larch	P Larch	BP Oak	P Oak	BP Linden	P Linden	BP Hornbeam	P Hornbeam	P Idling	P Max. RPM	BP Max. RPM
BP Beech	—	0.0000	1.0000	0.0000	1.0000	0.0000	0.0068	0.0000	1.0000	0.0000	0.0153	0.0000	0.000003	0.0000	0.0006
P Beech	0.0000	—	0.0000	1.0000	0.0000	1.0000	0.0004	1.0000	0.0000	1.0000	0.0001	1.0000	1.000000	1.0000	1.0000
BP Pine	1.0000	0.0000	—	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	0.001716	0.0001	0.0840
P Pine	0.0000	1.0000	0.0000	—	0.0000	1.0000	0.0002	1.0000	0.0000	1.0000	0.0001	1.0000	1.000000	1.0000	1.0000
BP Larch	1.0000	0.0000	1.0000	0.0000	—	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	0.000980	0.0006	0.0555
P Larch	0.0000	1.0000	0.0000	1.0000	0.0000	—	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.000000	1.0000	1.0000
BP Oak	0.0068	0.0004	1.0000	0.0002	1.0000	0.0000	—	0.0008	1.0000	0.0000	1.0000	0.0000	0.867235	0.1213	1.0000
P Oak	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0008	—	0.0000	1.0000	0.0002	1.0000	1.000000	1.0000	1.0000
BP Linden	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	—	0.0000	1.0000	0.0000	0.019026	0.0016	0.5505
P Linden	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	—	0.0000	1.0000	1.000000	1.0000	1.0000
BP Hornbeam	0.0153	0.0001	1.0000	0.0001	1.0000	0.0000	1.0000	0.0002	1.0000	0.0000	—	0.0000	0.4928	0.0612	1.0000
P Hornbeam	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	—	1.0000	1.0000	0.0831
P Idling	0.0000	1.0000	0.0017	1.0000	0.0010	1.0000	0.8672	1.0000	0.0190	1.0000	0.4928	1.0000	—	1.0000	1.0000
P Max. RPM	0.0000	1.0000	0.0001	1.0000	0.0001	1.0000	0.1213	1.0000	0.0016	1.0000	0.0612	1.0000	1.0000	—	1.0000
BP Max. RPM	0.0006	1.0000	0.0840	1.0000	0.0555	1.0000	1.0000	1.0000	0.5505	1.0000	1.0000	0.0831	1.0000	1.0000	—

Note: < 0.05 = operations difference (red).

Table 3. Results of statistical comparison – Rear handle.

Chainsaw/tree species	BP Beech	P Beech	BP Pine	P Pine	BP Larch	P Larch	BP Oak	P Oak	BP Linden	P Linden	BP Hornbeam	P Hornbeam	P Idling	P Max. RPM	BP Max. RPM
BP Beech	—	0.0000	0.9988	0.0000	1.0000	0.0000	0.0079	0.0000	0.1784	0.0000	0.6642	0.0000	0.0013	0.0000	0.1710
P Beech	0.0000	—	0.0001	1.0000	0.0000	1.0000	0.0041	1.0000	0.0023	1.0000	0.0000	1.0000	1.0000	1.0000	0.6481
BP Pine	0.9988	0.0001	—	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0022	1.0000
P Pine	0.0000	1.0000	0.0000	—	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	0.0292
BP Larch	1.0000	0.0000	1.0000	0.0000	—	0.0000	0.6412	0.0000	1.0000	0.0000	1.0000	0.0000	0.0494	0.0000	1.0000
P Larch	0.0000	1.0000	0.0000	1.0000	0.0000	—	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.2069	1.0000	0.0030
BP Oak	0.0079	0.0041	1.0000	0.0000	0.6412	0.0000	—	0.0006	1.0000	0.0008	1.0000	0.0000	1.0000	0.0304	1.0000
P Oak	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0006	—	0.0003	1.0000	0.0000	1.0000	1.0000	1.0000	0.1568
BP Linden	0.1784	0.0023	1.0000	0.0000	1.0000	0.0000	1.0000	0.0003	—	0.0004	1.0000	0.0000	1.0000	0.0145	1.0000
P Linden	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0008	1.0000	0.0004	—	0.0000	1.0000	1.0000	1.0000	0.1217
BP Hornbeam	0.6642	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	—	0.0000	1.0000	0.0007	1.0000
P Hornbeam	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	0.0000	—	0.6119	1.0000	0.0102
P Idling	0.0013	1.0000	1.0000	1.0000	0.0494	0.2068	1.0000	1.0000	1.0000	1.0000	1.0000	0.6119	—	1.0000	1.0000
P Max. RPM	0.0000	1.0000	0.0022	1.0000	0.0000	1.0000	0.0304	1.0000	0.0145	1.0000	0.0007	1.0000	1.0000	—	0.6218
BP Max. RPM	0.1710	0.6481	1.0000	0.0292	1.0000	0.0030	1.0000	0.1568	1.0000	0.1217	1.0000	0.0102	1.0000	0.6218	—

Note: < 0.05 = operations difference (red).

values of this chainsaw at all times differed when compared with the petrol chainsaw. The greatest difference in the average levels of vibrations could be localized on the front handle when compared with the cutting of linden, i.e. 3.4573 m/s^2 in favour of the petrol chainsaw. In case of the rear handle, the difference was 2.7640 m/s^2, but that was a comparison with the petrol chainsaw when cutting larch. Apart from the petrol chainsaw, different levels of vibrations were demonstrated also with the use of battery-powered chainsaw when cutting beech in its maximum working rotations at non-cutting the tree species samples.

In our research, we also compared vibrations produced in cutting beech with the petrol chainsaw the average level of which on the front handle was 2.1410 m/s^2 and the average vibration level on the rear handle was 2.5766 m/s^2 with the other activities. In total, a difference was recorded in seven cases of 13, with 5 of them including the use of the battery-powered chainsaw at cutting different tree species. The greatest difference in the average vibration level acting on the front handle was achieved in the comparison with the petrol chainsaw on pine. The difference was 2.6860 m/s^2 in favour of the petrol chainsaw on pine. On the other hand, the least difference on the front handle was 0.2702 m/s^2, and was recorded in the comparison with the idling petrol chainsaw. The rear handle and its average vibration level differed most by 1.8866 m/s^2 and least by 0.4447 m/s^2. In both cases, the operator was affected by higher vibrations when the battery-powered chainsaw was used.

Another vibration level compared with the other ones was recorded at cutting pine with the petrol chainsaw. Mean vibration values acting on the front and rear handles respectively were 4.8270 m/s^2 and 3.8867 m/s^2 (Tab. 4). There were altogether twelve combinations with different data being recorded in 7. Results of the statistical analysis showed nearly in all cases a difference in combinations compared with the petrol chainsaw. The levels of vibrations differed only in one combination when comparing vibrations on the front and rear handles at maximum rotations of the petrol chainsaw. Comparing vibrations on the front handle we found out that the greatest difference between the mean levels of vibrations was recorded in the petrol chainsaw at cutting hornbeam (3.3148 m/s^2) to the detriment of the battery-powered chainsaw. The least difference (1.9370 m/s^2) was observed in the comparison with the battery-powered chainsaw at maximum rotations when this chainsaw generated a higher level of vibrations. In the rear handle and its comparison of mean vibration values, the greatest difference was 1.8557 m/s^2 and the least difference was 0.5354 m/s^2.

A comparison of vibrations produced by different chainsaws, tree species and handles were made when cutting pine with the petrol chainsaw. There were altogether eleven comparisons of which six were classified as different. It was found that the values of vibrations at cutting any tree species were always different when compared with the battery-powered chainsaw. The petrol chainsaw always reached lower values. Different vibrations were also demonstrated in the combination of petrol chainsaw in idle run and battery-powered chainsaw in maximum rotations. Mean vibrations acting on the front and rear handles at cutting pine with the petrol chainsaw was 1.9381 m/s^2 and 2.2023 m/s^2, respectively. A maximum difference in the mean vibration levels on the front or rear handle was recorded when compared with the vibrations of battery-powered chainsaw when cutting larch. A minimum difference between the mean levels of vibrations on the front and rear handles was also recorded when compared with the petrol chainsaw in idle run.

The following level of vibrations was the one which was generated by the battery-powered chainsaw when cutting larch. Mean vibrations on the front and rear handles during the cutting were 4.6854 m/s^2 and 4.4631 m/s^2, respectively (Table 4). There were altogether ten combinations of which seven were classified as different. Results of the statistical analysis demonstrated a difference from the battery-powered chainsaw almost at all times. Vibrations differed also in the petrol chainsaw only in one situation when it reached the maximum working speed. Comparing the values of vibrations on the front handle we found out that compared with the petrol chainsaw, the greatest difference between the petrol chainsaw when cutting hornbeam was 3.3732 m/s^2 to the detriment of the battery-powered chainsaw. The least difference was recorded when compared vibration levels from the maximum rotations of the battery-powered chainsaw, which were lower by 1.7954 m/s^2. On the rear handle, a minimum difference was recorded in the same activity as on the front handle but its value was 1.1119 m/s^2. The mean values of vibrations which differed the most were those on the rear handle when compared with the petrol chainsaw on larch, which produced vibrations by 2.4351 m/s^2 lower than the battery-powered chainsaw at cutting larch.

Vibrations of the petrol chainsaw at cutting larch were compared with the other vibrations values. There were altogether nine comparisons and a statistical difference was recorded in 5 of them. During the measurements the front and rear handles transmitted onto the operator mean vibration levels of 1.8672 m/s^2 and 2.0223 m/s^2, respectively. The greatest difference between the mean values of vibrations on the front handle was recorded when compared with the battery-powered chainsaw whilst cutting linden with the petrol chainsaw that was reaching lower values. A small difference was observed in the comparison with the petrol chainsaw in idle run, which produced lower vibration values. Comparing the rear handle, a maximum difference was 1.7581 m/s^2 and was recorded when cutting hornbeam. Also in this case, the petrol chainsaw reached lower values. The smallest difference in the mean vibration level recorded on the rear handle was observed in the comparison with the petrol chainsaw in idle run (0.9933 m/s^2), but the result was identical with the front handle.

Table 4. Descriptive statistics.

Chainsaw / tree species	Mean value [m/s²]	Median [m/s²]	Mode [m/s²]	Frequency of mode	Min. [m/s²]	Max. [m/s²]	Standard deviation [m/s²]
BP Beech FH	5.2986	5.5800	Multiple	2	2.5200	7.6900	1.2107
P Beech FH	2.1410	2.1700	1,3600	2	0.9000	3.8100	0.7114
BP Beech RH	4.7920	5.0200	5,5800	2	2.7700	6.8500	1.0060
P Beech RH	2.5766	2.3700	Multiple	2	1.2600	5.0600	0.8502
BP Pine FH	4.8270	4.4900	3,7800	2	1.2300	8.8500	1.7001
P Pine FH	1.9381	1.6800	Multiple	2	0.8400	5.5100	0.9342
BP Pine RH	3.8867	3.9000	Multiple	2	1.1500	6.3900	1.1733
P Pine RH	2.2023	2.0400	2,5500	2	1.2500	4.3700	0.6793
BP Larch FH	4.6854	4.7100	Multiple	2	1.3900	6.7700	1.3158
P Larch FH	1.8672	1.4700	1,6200	2	0.7900	5.8900	1.2647
BP Larch RH	4.4631	4.3100	4,7200	2	1.5300	6.7800	1.1822
P Larch RH	2.0280	1.9600	Multiple	2	1.2500	3.0700	0.3973
BP Oak FH	3.5168	3.4700	2,8500	3	1.1500	5.0500	0.7388
P Oak FH	2.0888	1.8600	Multiple	1	0.8900	4.3700	0.8157
BP Oak RH	3.4386	3.4600	Multiple	2	1.0200	5.1100	0.6669
P Oak RH	2.4134	2.4500	Multiple	2	1.2800	5.3500	0.7374
BP Linden FH	4.2097	4.0850	4,0600	2	2.4200	6.8400	1.0568
P Linden FH	1.8413	1.3450	Multiple	1	0.9100	5.1200	1.1196
BP Linden RH	3.6291	3.5300	4,0500	2	1.1800	6.1900	0.9489
P Linden RH	2.3417	2.2650	Multiple	1	1.3200	5.5400	0.8686
BP Hornbeam FH	3.6415	3.8150	Multiple	2	1.0400	5.6700	0.9595
P Hornbeam FH	1.5122	1.4550	Multiple	2	0.7400	3.1900	0.5093
BP Hornbeam RH	3.7861	3.7800	Multiple	2	1.0500	6.2500	0.8540
P Hornbeam RH	2.1463	2.1350	1,4500	3	1.0100	4.8400	0.7721
P Idling FH	2.4113	2.5600	1,5200	2	1.5200	3.1800	0.5182
P Idling RH	3.0213	3.0000	Multiple	1	2.7500	3.4300	0.1884
P Max. RPM FH	2.1744	2.1250	Multiple	1	1.4100	2.8600	0.3805
P Max. RPM RH	2.3969	2.4300	Multiple	1	1.5500	3.3900	0.4820
BP Max. RPM FH	2.8900	2.9350	Multiple	1	1.2500	5.8300	1.1110
BP Max. RPM RH	3.3513	3.4700	Multiple	1	2.2100	4.3200	0.5713

Another comparison included vibration levels generated by the battery-powered chainsaw when cutting oak. This level was compared eight times and was evaluated as different in six cases. Mean vibrations affecting the operator on the front and rear handles were 3.5168 m/s² and 3.4386 m/s², respectively (Table 4). The values of vibrations on the front handle differed the most when compared with the values of vibrations recorded from cutting hornbeam by the petrol chainsaw (2.0046 m/s²) in favour of the petrol chainsaw. The smallest difference in the mean vibration values was recorded in the comparison with the values of battery-powered chainsaw at maximum rotations (0.6268 m/s²) in favour of the battery-powered chainsaw at maximum rotations. In these comparisons, minimum and maximum differences between vibrations on the rear handle were 0.0874 m/s² and 1.2924 m/s², respectively. In both cases, the higher vibration levels were recorded in the battery-powered chainsaw when cutting oak.

Then, vibrations generated by the petrol chainsaw when cutting oak were compared with the other vibration levels. The statistical comparison included seven cases of which four were classified as different. The mean value of vibrations recorded on the front and rear handles of the petrol chainsaw when cutting oak was 2.0888 m/s² and 2.4134 m/s², respectively. The greatest differences in the comparisons were recorded on the front handle when compared with the battery-powered chainsaw whilst cutting linden, and on the rear handle when compared with the battery-powered chainsaw when cutting hornbeam. The smallest difference in the comparison of either front or rear handles was recorded identically in the comparison with the petrol chainsaw in idle run. In all cases, the petrol chainsaw reached lower vibration levels when cutting oak.

Vibration levels were also compared whilst cutting linden with the battery-powered chainsaw. There were altogether six comparisons of which five were classified as different. The average value of vibrations recorded on the front and rear handles when cutting linden was 4.2100 m/s² and 3.6290 m/s², respectively (Tab. 4). The greatest difference compared with the other vibration values was recorded on both handles when cutting hornbeam with the petrol chainsaw. Minimum differences in the different vibration values on the front and rear handles were recorded when compared with the maximum rotations of the battery-powered chainsaw. The differences on the front handle were 1.3202 m/s² in favour of the battery-powered chainsaw in maximum rotations. The same situation was in case of the rear handle where the difference was 0.2778 m/s².

The research further included a comparison of vibrations produced by the petrol chainsaw when cutting linden with the other vibration levels. There were altogether five combinations of which three were classified as different. Mean vibrations recorded on the front handle (1.8413 m/s²) and on the rear handle (2.3417 m/s²) differed the most when compared with the level of vibrations generated by the battery-powered chainsaw when cutting hornbeam. The petrol chainsaw vibrations were by 1.8002 m/s^2 lower on the front handle and by 1.4444 m/s^2 lower on the rear handle. The smallest difference in both handles was found when compared with the petrol chainsaw at idle run when the front handle reached the vibration levels higher by 0.5700 m/s^2 and the rear handle reached the vibration levels higher by 0.68080 m/s^2.

Vibrations recorded when cutting hornbeam by the battery-powered chainsaw were also compared with the other vibration levels. There were altogether four combinations of which all were classified as different. The greatest difference in mean values was recorded on the front and rear handles when compared with the petrol chainsaw when cutting hornbeam. The battery-powered chainsaw reached the vibration levels higher by 2.1293 m/s^2 on the front handle and by 1.6400 m/s^2 on the rear handle. A minimum difference in vibrations on the front and rear handles was identically recorded in comparison with the battery-powered chainsaw in maximum rotations, which reached lower levels: by 0.7515 m/s^2 on the front handle and by 0.4348 m/s^2 on the rear handle.

Following this, vibrations generated in the petrol chainsaw when cutting hornbeam were compared with the other vibration levels. There were three combinations of which all three were classified as different. Mean vibrations recorded on the front and rear handles of the petrol chainsaw when cutting hornbeam were 1.6233 m/s^2 and 2.1463 m/s^2, respectively. Mean vibrations differed the most when compared with the petrol chainsaw in maximum rotations and mean vibrations differed the least when compared with the battery-powered chainsaw in maximum rotations. The greatest difference in vibration levels on the front handle was 1.3778 m/s^2 and 1.2050 m/s^2 on the rear handle. The least difference on the front handle was 0.6622 m/s^2 and 0.2506 m/s^2 on the rear handle. In both cases, lower vibration levels were at all times reached by the petrol chainsaw when cutting hornbeam.

The research results further showed that the petrol chainsaw in idle run mode generates vibration levels that differ in 1 of 2 comparisons. Mean vibrations recorded on the front and rear handles were 2.4113 m/s^2 and 3.0213 m/s^2, respectively. The statistical analysis demonstrated the different values of vibrations when compared with vibrations generated by the petrol chainsaw in maximum rotations. The petrol chainsaw in maximum rotations generates on the front handle vibrations lower by 0.2369 m/s^2 than in idle run. The same result was recorded also on the rear handle where the difference was 0.6244 m/s^2. The last and only combination in the comparison of vibration levels was the comparison of values from the measurements of petrol chainsaw and battery-powered chainsaw in maximum rotations with the first mentioned chainsaw reaching lower values.

4. Discussion

The vibration level of the battery-powered chainsaw Stihl MSA 200C claimed by the manufacturer on the front and rear handles is 3.9–4.6 m/s^2 (Stihl 200C). This battery-powered chainsaw was used in our research. Mean vibration levels recorded in our research for this type of chainsaw ranged from 3.5168 to 5.2986 m/s^2 on the front handle and from 3.4386 to 4.7920 m/s^2 on the rear handle. Comparing the values claimed by the manufacturer and the values recorded in our research, it can be seen that levels observed in our research were higher. For the petrol chainsaw Stihl MS 170 involved in our research the manufacturer claims vibration levels on the front and rear handles ranging from 5.2 to 5.5 m/s^2 (Stihl 170). Mean vibration levels recorded in our research on the front handle ranged from 1.5122 to 2.1410 m/s^2 and from 2.0280 to 2.5766 m/s^2 on the rear handle. The values claimed by the manufacturer are in all cases higher than values recorded in this research. The highest vibration levels recorded by us when cutting individual tree species ranged from 3.0700 to 5.8900 m/s^2 in this chainsaw. Thus, it can be seen that also these values are in several cases lower than claimed by the manufacturer.

The Czech legislation specifies a hygiene limit for exposure to HAV for 20 minutes or less of 12.5 m/s^2 (Nařízení vlády 2011). Looking at the maximum values that were recorded in this research, it is evident that this value was not exceeded in this research.

Results of research conducted by Landekić et al. (2020) showed that groups of lower and medium performance class chainsaws powered by petrol (Stihl MS 260 and Stihl MS 440) have the highest vibration levels recorded most frequently on the front handle while the Stihl MS 660 chainsaw which belongs in the higher performance class had the highest measured vibration levels on the rear handle. Results of this research showed that the Stihl MS 170 petrol chainsaw measured by us exhibited higher mean vibration levels on the rear handle, which does not correspond with the results of Landekić et al. (2020). On the other hand, research conducted by Feyzi et al. (2016) with the Stihl MS 230 petrol chainsaw of lower performance class revealed the highest vibration levels on the rear handle, which corresponds with the results of our research.

Poje et al. (2018) state that the operator of battery-powered chainsaw is affected by lower exposure to HAV when cutting wood. These authors claim that HAV exposure using the battery-powered chainsaw is on average 1.23 m/s^2 lower (Poje et al. 2018) compared to a petrol chainsaw. The fact that exposure to HAV in the battery-powered chainsaw is lower than in the petrol chainsaw is corroborated also by Neitzel & Yost (2002). The findings of Poje et al. (2018) and Neitzel & Yost (2002) do not correspond with the results of this research in which the authors found an opposite situation, i.e. that the petrol chainsaw generates lower values of exposure to HAV than the battery-powered chainsaw. However, in the research by Neri et al. (2018) and Neitzel & Yost (2002), the same conditions for the above factors were not fully met. In these research studies, different chainsaws were compared in terms of weight, number of handles or length of chains or bars, and chainsaw power. In most cases, these parameters were lower for electric or cordless chainsaws. The results of our research are however agreed by Rukat et al. (2018) who recorded in their research accelerated levels of vibrations on the front and rear handles that were higher in battery-powered chainsaws when compared with petrol chainsaws.

The effect of tree species on emissions of vibrations was studied by several authors (e.g., Rottensteiner et al. 2012; Huber et al. 2021; Papandrea et al. 2022). Conclusions of their studies indicate that softwoods exhibit lower cutting resistance, which results in the lower production of vibrations than hardwoods. Goglia et al. (2012b) agree with the statement and add that HAV differ at cutting diverse tree species and are higher in the species of higher wood density. Rottensteiner et al. (2012) also evaluated the effect of tree species on exposure to vibrations. Their results confirmed that vibration emissions increase with the increasing wood density. Authors of this research agree with the statement of the above authors that operators are affected by different HAV levels at cutting diverse tree species with the chainsaw (battery-powered as well as petrol types). In contrast to that, Kováč et al. (2018) made an analysis of the frequency-weighted acceleration of vibrations, which did not show any difference of vibration levels among the compared tree species including beech (*Fagus sylvatica* L.) and spruce (*Picea abies* [L.] Karst.). A similar opinion was published by Neri et al. (2023) in whose research the battery-powered chainsaw produced similar vibration levels for two tested species of Austrian pine (*Pinus nigra* Arnold) and European beech (*Fagus sylvatica* L.). Similar vibration levels were recorded by the same author also on both handles (Neri et al. 2023).

Factors that must be mentioned and that may affect vibration levels in chainsaws are wood density (Rottensteiner et al. 2012) but also chain tension, angle of chain sharpening, bar length, fuel amount in the tank or strength of chainsaw handle grip (Goglia et al. 2012b; Malinowska-Borowska et al. 2012; Rottensteiner et al. 2012; Malinowska-Borowska & Zieliński 2013; Marenče et al. 2017; Yovi & Yamada 2019). All these factors were eliminated in our research or at least limited by the fact that all tree species subjected to cutting featured the same diameter and the same wood moisture content. Other factors were eliminated or restricted by the fact that all cutting operations were done using the same saw chain and the same saw bar. The fuel tank in the petrol chainsaw was kept full for the entire time of cutting, which reduced the fuel movement in the tank. The factor of different strength of chainsaw handle grip was kept under control by the cutting of all trees being performed by one and the same operator.

5. Conclusion

In our research, vibration levels were recorded acting on the operators of petrol and battery-operated chainsaws when cutting logs of diverse tree species. Vibration levels on the front and rear chainsaw handles were then compared. The highest measured value (8.8500 m/s^2) was recorded on the front handle of the battery-powered chainsaw at cutting pine. The lowest measured value (0.7400 m/s^2) was recorded on the front handle with the petrol chainsaw, again when cutting hornbeam. As to the rear handle, one can see higher vibration levels with a minimum being 1.0100 m/s^2. The operator was exposed to this vibration level again when cutting hornbeam with the petrol chainsaw. The highest vibration level measured on the rear handle was 6.8500 m/s^2 when cutting beech with the battery-operated chainsaw.

In our research, we also compared vibration levels produced by the petrol chainsaw and battery-powered chainsaw by the same manufacturer at cutting diverse tree species. There were altogether 105 possible combinations of which 67 were classified in the statistical test as different (63.81%). The research results indicate that vibration levels produced by the battery-powered chainsaw were higher than vibration levels produced by the petrol chainsaw. The vibration levels of the petrol chainsaw ranged mostly from 1.0000 to 3.0000 m/s^2 while the vibration levels of the battery-powered chainsaw ranged from 3.0000 to 6.0000 m/s^2. In summary, therefore, the vibration of a petrol chainsaw is lower than that of a battery-powered chainsaw, but this finding applies to one manufacturer. In the future, this claim should be verified with other manufacturers.

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